OPIC
OFFICE DE LA PROPRIÉTÉ INTELLECTUELLE DU CANADA

CIPO
CANADIAN INTELLECTUAL PROPERTY OFFICE

(12) (19) (CA) **Demande-Application**

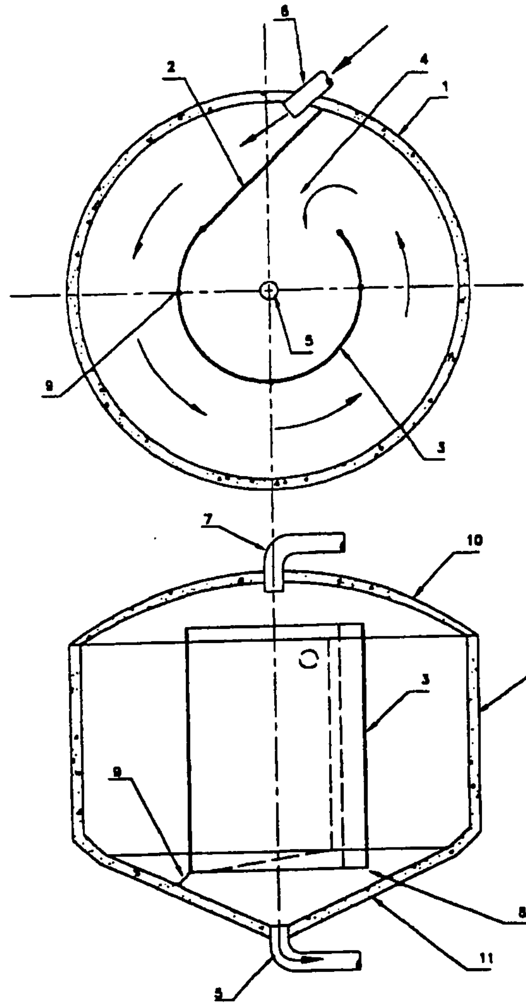
(21) (A1) **2,259,673**
(22) 1999/01/14
(43) 2000/07/14

(72) LEVIN, Andrey, CA
(71) LEVIN, Andrey, CA

(51) Int.Cl.[6] C02F 11/04

(54) **METHODE ET APPAREIL POUR LA DIGESTION ANAEROBIE DE DECHETS ORGANIQUES**

(54) **METHOD AND APPARATUS FOR ANAEROBIC DIGESTION OF ORGANIC WASTES**



(57) Presented method of anaerobic digestion of high-solid mixes of organic wastes comprises of two consequent stages of digestion which are carried out in same temperature mode: primary digestion in conventional high-rate anaerobic digester with completely mixed media, followed by digestion of partly digested and sufficiently seeded effluent from primary digester in longitudinally-shaped consequent-flow digester. Also provided: the design of spiral-winded consequent-flow digester, comparison of invented and conventional schemes of digestion, example of organic wastes treatment plant, etc.

Industrie Canada Industry Canada

BACKGROUND OF THE INVENTION

Technology of anaerobic digestion of organic materials, mostly wastes like sewage sludge and livestock manure, is in intensive use for more than 70 years. The possibility to produce energy from organic material by anaerobic digestion periodically (mainly during oil crisises) attracts attention of scientists and designers, but its application solely for energy production never was feasible economically, and to my mind never will be. Nevertheless combined goals of:

a) elimination of huge amount of wastes;
b) transfer of waste in useful fertilizer;
c) recovery of energy stored in organic material;

promise extreme profitability of this process applied to treat all collectible organic wastes. According to numerous researches, quantity of readily collectible clean organic wastes in developed countries reached amount of one dry ton per capita annually. Major sources of organic wastes, fully suitable for anaerobic digestion and transferable to unpolluted fertilizer, are (dry kg per capita annually):

a) liquid wastes, rich in nitrogen:
   1) sewage sludge - 50;
   2) livestock manure - 250;
   3) food industry waste - 60;
b) solid wastes, rich in carbon:
   1) yard waste - 220;
   2) lumber industry waste - 80;
   3) agricultural waste (easily collectible) - 300.

Recent trends of extremely tight environmental legislation, shortage of available dumping sites, ban on yard waste dumping to municipal landfills, high price of discharging (dumping in modern landfill – up to US$ 80, clean incineration – up to US$ 120 per wet ton), inspire extensive application of aerobic composting plants, which proved itself the cheapest method of organic waste handling. However, anaerobic digestion promises some important advantages in contrast to aerobic composting:

a) energy recovery (up to 250 L liquid fuel equivalent per 1 dry ton of waste processed, in form of the cleanest hydrocarbon fuel – methane gas);

b) possibility to use existed and conveniently located anaerobic digesters on sewage treatment plants (established digester volume 30 - 80 L per capita, enough to handle approximately 500 dry kg waste annually);
c) provides easier odor control and assures complete destruction of pathogenic bacteria;
d) reduces emission of greenhouse gases – carbon dioxide (replaces equivalent amount of fossil fuel combusted) and methane (20 - 30 times more powerful greenhouse agent than carbon dioxide).

My further calculations will be based on some issues and parameters gained worldwide during successful operation of pilot full-scale anaerobic digesters of organic wastes (including mix of sewage sludge and putrescible fraction of municipal waste):
a) mix of solid/liquid wastes provides perfect feed for anaerobic microorganisms because of its optimum carbon/nitrogen ratio (around 20:1);
b) maximum concentration of feed sludge should not exceed 20% total solids (TS) for easier pumping;
c) maximum concentration of sludge in digester should be approximately 10% TS for easier mixing and biogas liberation.

Key parameter of successful anaerobic digestion is to maintain tight equilibrium between two major populations of microorganisms: acidogenics and methanogenics. Acidogenics have higher rate of reproduction than methanogenics and during overloading produce more volatile acids (mainly acetic) than methanogenics could consume, resulting in the drop of pH of the sludge below equilibrium level of 6.8 - 7.5 and inhibits methanogenes. That is why:
d) all incoming sludge should be intensively seeded by active microorganisms, and
e) minimum retention time of sludge in digester should be 4 days (mesophilic range of operation) to prevent wash-out of methanogenics, while maintaining limited food supply conditions for acidogenics.

In fact, anaerobic digesters operate with significantly longer retention time (20 and more days) to produce better digested sludge. The problem is: the shorter retention time, the higher proportion of "yesterday" underdigested sludge is presented in effluent. To solve this problem some inventors (US patents US05451319, US04514297, and US05389258) propose consequent-flow digesters, where load of raw sludge moves in longitudinal direction of long-shaped digester from intake to discharge port. To provide sufficient seed of the influent they recycle part of digested sludge to mix with raw sludge influent. Unfortunately, high rate of recycling (about 50%) swept out almost all advantages of this method.

The method incorporating two digesters connected in series (US05525228 and WO9738945) inherently decreases by two times quantity of "yesterday" sludge in final effluent. This increase in efficiency allows to switch primary so-called high-rate digester to thermophilic mode without unacceptable increase in external heating. Nevertheless, second stage digester due to weak digestion intensity (and consequently weak internal heat release) continues to operate under mesophilic temperature. Proposed invention allows double increase efficiency of the secondary digester and so opens possibility to transfer secondary digester to thermophilic mode too.

DESCRIPTION OF METHOD

Present invention proposes two-stage digestion scheme. Raw sludge enters high-rate digester with completely mixed media. Retention time is maintained minimal to support digestion. Partly digested and extensively seeded effluent from high-rate digester is routed to secondary digester which operates in same temperature mode (thermophilic or mesophilic) like high-rate one. Secondary digester is performed in sufficiently longitudinal shape (pipe or channel, for example) to maintain consequent flow of sludge from intake to discharge port, and so to assure that any part of final effluent was retained in consequent-flow digester during all operational retention time.

In case of overloading of high-rate digester, portion of final effluent from consequent-flow digester is routed to high-rate digester to provide additional "hungry" methanogenic microorganisms to consume the overloading.

Proposed scheme is fully applicable to two stage fermentation scheme with separate vessels to carry out acidification and methanization. In this case invented scheme comprises of series of three digesters in fluid communication: first is hydrolyzing and acidifying digester, second is high-rate methanogenic digester, and third is consequent-flow methanogenic digester. Last two digesters should operate in same temperature mode.

To compare invented and conventional methods I use simple but sufficiently correct to aim of comparison model of constant half-digestion time of sludge. Lets assume that dry raw sludge consists of (by weight):

40% indigestible material (IDM);
45% readily digestible material (RDM);
10% moderate digestible material (MDM);
5% hardly digestible material (HDM).

Digestible fraction undergoes digestion with constant half-digestion time of 1, 2, and 4 days respectively (or diminishes daily by coefficient K(I) equal to 2, 1.4, and 1.2 respectively). Feed of raw sludge is 500 ton with 20% TS concentration and is performed once a day after discharge of equivalent amount of digested sludge. Let X(I) is quantity of undigested (I) fraction of sludge in conventional high-rate digester exactly before discharging-feeding. After discharging quantity of said fraction will be $X(I)(1-1/D)$, after feeding - $X(I)(1 - 1/D) + A(I)$, where A(I) - daily feed of fraction (I) and D - retention time of sludge in digester in days. During the day fraction (I) undergoes digestion with rate K(I) and becomes equal to initial quantity X(I):

$$((X(I)(1 - 1/D) + A(I)) /K(I)= X(I) \qquad (1)$$

or: $$X(I) = A(I)/(K(I) - 1 + 1/D).$$

The results of calculations for 4-day entirely mixed digester is presented in Table 1, where W is water, E(I) is quantity of fraction (I) in effluent, TSD is TS concentration in digester, and ROD is rate of digestion for digestible materials. The results for different retention times are presented in Table 2.

Lets further assume that effluent from 4-day digester enters secondary conventional digester (entirely mixed), and apply equation (1) to the load of 9, 4, and 3 ton of RDM, MDM, and HDM respectively to said digester. The results are presented in

Table 3. As you see, two digesters connected in series reach digestion rate of 93.6% in 4+6=10 days, while one stage digester reaches digestion rate of 93% in 20 days.

Lets further assume that effluent from primary 4-day high-rate digester enters invented consequent-flow digester and undergoes digestion with daily digestion rate of K(l). The results of calculation is presented in Table 4. As you see, invented combination of two digesters reaches digestion rate of 94.9% in 4+4=8 days, while combination of conventional digesters reaches digestion rate of 94.8% in 4+8=12 days. Invented method is 1.5 times more efficient, and second stage of invented method is 2 times more efficient than conventional one.

DESCRIPTION OF APPARATUS

Invented consequent-flow secondary digester is described in Figure 1. To maintain minimal surface-to-volume ratio (to minimize heat loses) and allow simple modification of conventional cylindrical sewage sludge digesters, invented digester is shaped in form of spiral winded channel. Said digester has cylindrical outer wall (1), sloped to the center bottom (11), cover (10) with biogas withdrawal port (7), and discharge port (5) of digested sludge in the center of the bottom. This traditional design is fitted with light inner vertical wall (2) and (3) from bottom to upper level of sludge. The shape of the inner wall remains digit "6", and guides sludge flow from intake port (6), situated in the outer wall of digester, between outer and inner walls consequently along straight part (2) of the inner wall, around cylindrical part (3) of the inner wall, throw the opening (4) in the inner wall to internal cylindrical compartment and further to the bottom discharge port (5). Directions of sludge flow is described by arrows. The inner wall is mounted on stands (9) so to leave horizontal slot (8) to free slide of sedimented sand and grit from outer compartment of digester directly toward the bottom discharge port. Described digester could be fitted with all conventional equipment which include:

a) sludge heaters;
b) local sludge mixers, include biogas recycling stacks;
c) port for scum removal;
d) port for supernatant removal;
e) scum breakers and foam suppressers;
f) outer walls heat insulation;
g) bottom sediment scraper;
h) lime addition devises;
i) surface scum skimmer, etc.

Cylindrical shape of the outer and inner walls easily allows to modificate conventional radial scum skimmer and sediment scraper to fit invented digester. High TS concentration (approximately 10%) assures minimal stratification of sludge and its laminar flow from inlet to discharge port.

SCHEME OF SOLID WASTES TREATMENT PLANT

Example of organic wastes complex treatment plant is presented in Figure 2. Solid waste (1) goes to grinder (2) and mixes with supernatant (15) and liquid waste (5) in mixer (4).

Raw sludge (6) with TS 20% goes to accumulation tank (7), where it undergoes initial stages of homogenization, hydrolysis, and liquifation. This tank is necessary for controling of raw sludge flow and for removing of remaining atmospheric oxygen, which is toxic to methanogenic microorganisms. Pretreated raw sludge (8) enters high-rate digester (9) and after digestion partly digested sludge (10) with TS 12% goes to consequent-flow digester (11). Digested sludge (12) with TS 10% goes to belt press(14). In case of overloading of high-rate digester portion of digested sludge (13) is directed to high-rate digester to dissolve the overload. Compacted sludge (16) with TS 20% from belt press goes to dryer (17), and dried to 80% TS digested sludge is ready to packing to be sold as organic fertilizer (18). Biogas (19) from digesters (9) and (11) goes to biogas scrubber (20), where hydrogen sulfide and excessive carbon dioxide and water vapors are removed. Conditioned biogas (21) goes to combustion turbine (22) (or steam boiler, or diesel bi-fuel engine), which rotates generator (23) and electricity (24) is produced. Exhaust gases (25) go to the dryer and dry the sludge (16). After dryer cooled gases (26) go to emission control devices (27) and cleaned gases (28) are discharged to atmosphere by stack (29). Temperature of exhaust gases (25) is approximately 400°C, and therefore this gases are ideally suitable to sludge dryer (for example - spray drier). Efficiency of combustion engine (22) is less then 40%, and remaining 60% of thermal energy (according to my calculations) is completely enough to dry all sludge and maintain heating of digesters (9) and (11). Heating of digesters could be maintained by transfer of hot engine coolant (30). Sure, described plant is economical only for big-volume installation.

CLAIMS

I claim:

1. The process of anaerobic digestion of organic material, comprises of two consequent stages:
   a) first stage digestion in high-rate digester with complete mixing of media and minimum possible retention time;
   b) followed by consequent-flow digestion in same temperature mode (thermophilic or mesophilic) of primary digested sludge from said primary high-rate digester in secondary digester with consequent flow of sludge along longitudinal-shaped channel from intake port to discharge port.
2. The system of claim 1, wherein in case of overloading of said primary high-rate digester part of digested sludge from discharge port of said secondary consequent-flow digester is directed to said primary high-rate digester and is mixed with its media to overcome its overloading.
3. The system of claim 1, wherein first stage digestion is divided into two stages - acidogenic and methanogenic, and is carried out in two separate vessels.
4. The system of claim 1, wherein said secondary consequent-flow anaerobic digester comprises of:
   a) cylindrical tank with hemispherical cover and sloped to the center bottom;
   b) inner vertical wall from bottom of said tank to upper level of sludge, which said wall goes by the chord from the side wall of said tank and further winds in circular

TABLE 1

	A(I), T	K(I)	X(I), T	E(I), T	TSD, %	ROD, %
IDM	40	–	160	40	12%	74%
RDM	45	2	36	9		
MDM	10	1.4	15.4	3.8		
HDM	5	1.2	11.1	2.8		
W	400	–	1600	400		

TABLE 2

	RETENTION TIME, DAYS				
	4	8	12	16	20
TSD, %	12	11	10.5	10	10
ROD, %	74	84	89	91	93

TABLE 3

	RETENTION TIME, DAYS			
	2	4	6	8
TSD, %	11	10.1	9.9	9.7
ROD, %	86	91.7	93.6	94.8

TABLE 4

	RETENTION TIME, DAYS			
	2	4	6	8
TSD, %	11	9.7	9.4	9.3
ROD, %	89.5	94.9	97.2	98.3

METHOD AND APPARATUS FOR ANAEROBIC DIGESTION OF ORGANIC WASTES

ABSTRACT

Presented method of anaerobic digestion of high-solid mixes of organic wastes comprises of two consequent stages of digestion which are carried out in same temperature mode: primary digestion in conventional high-rate anaerobic digester with completely mixed media, followed by digestion of partly digested and sufficiently seeded effluent from primary digester in longitudinally-shaped consequent-flow digester. Also provided: the design of spiral-winded consequent-flow digester, comparison of invented and conventional schemes of digestion, example of organic wastes treatment plant, etc.

CLAIMS

I claim:

1. The process of anaerobic digestion of organic material, comprises of two consequent stages:
   a) first stage digestion in high-rate digester with complete mixing of media and minimum possible retention time;
   b) followed by consequent-flow digestion in same temperature mode (thermophilic or mesophilic) of primary digested sludge from said primary high-rate digester in secondary digester with consequent flow of sludge along longitudinal-shaped channel from intake port to discharge port.
2. The system of claim 1, wherein in case of overloading of said primary high-rate digester part of digested sludge from discharge port of said secondary consequent-flow digester is directed to said primary high-rate digester and is mixed with its media to overcome its overloading.
3. The system of claim 1, wherein first stage digestion is divided into two stages - acidogenic and methanogenic, and is carried out in two separate vessels.
4. The system of claim 1, wherein said secondary consequent-flow anaerobic digester comprises of:
   a) cylindrical tank with hemispherical cover and sloped to the center bottom;
   b) inner vertical wall from bottom of said tank to upper level of sludge, which said wall goes by the chord from the side wall of said tank and further winds in circular

shape parallel to said side wall to form not closed cylinder with opening at the end to maintain spiral movement of sludge from

c) intake port of raw sludge situated in the said side wall of said tank near the connection of said side and inner walls on the opposite of said opening side of said inner wall, toward

d) the discharge port of digested sludge situated in the center of the bottom of said tank in the center of said internal not closed cylindrical compartment created by said winded inner wall;

e) the withdrawal port of generated biogas situated in said upper cover of said tank.

5. The system of claim 4, wherein said inner wall is uplifted to provide horizontal slot between said wall and said bottom of said tank to maintain free slide of sand and grit deposits on slopped bottom of said outer circular sludge compartment to said inner cylindrical compartment toward said digested sludge discharge port.

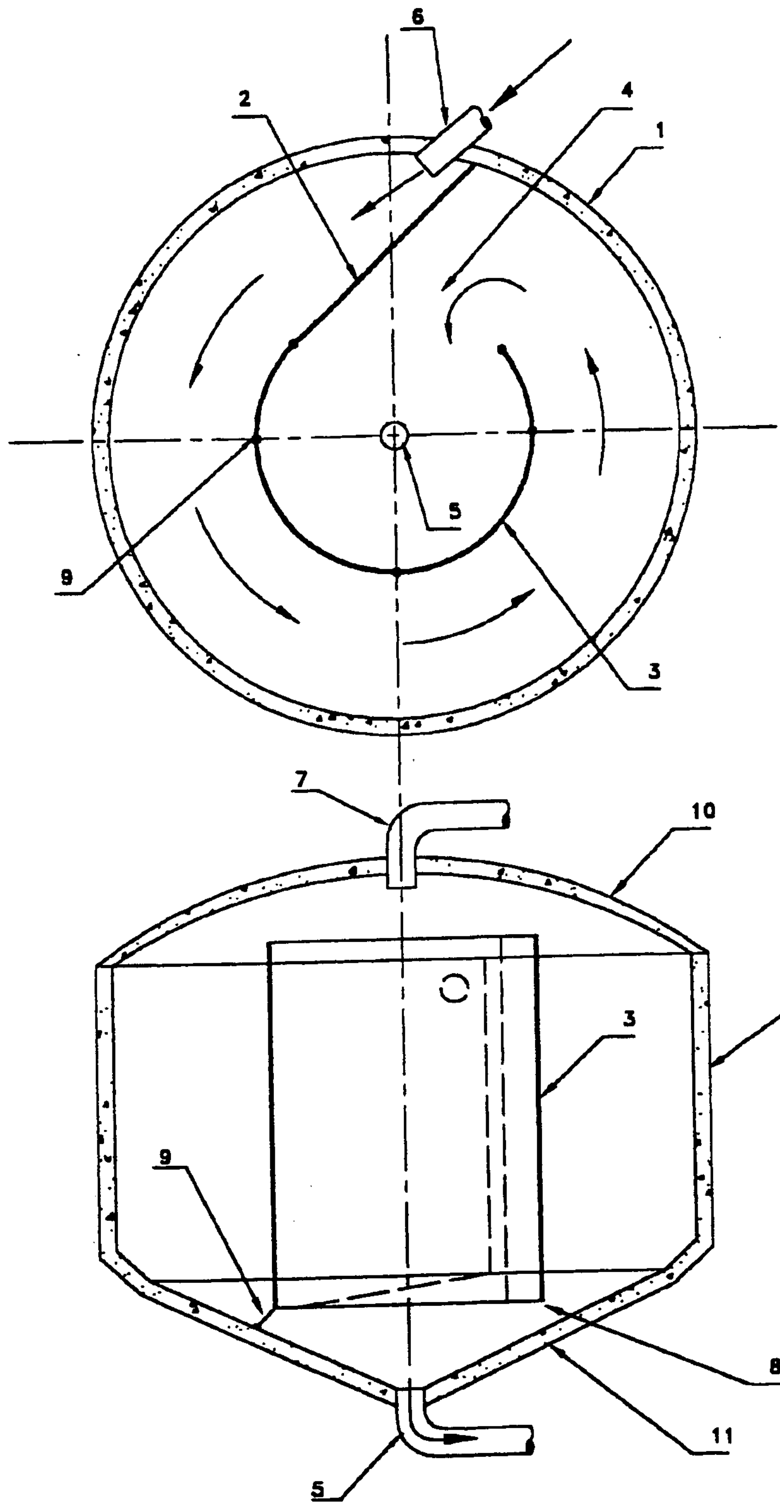
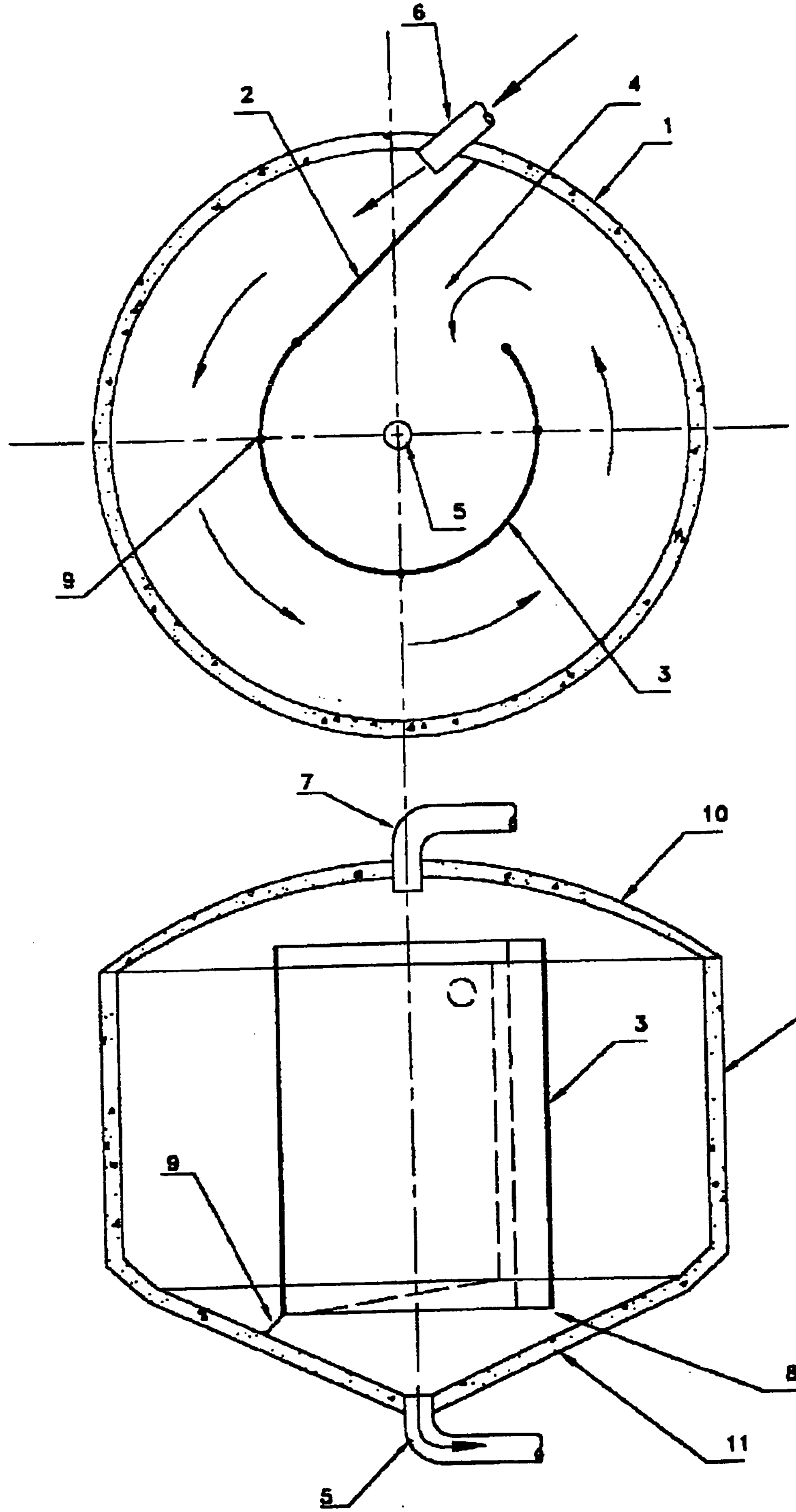


FIG.1


6
2
4
1
5
9
3
7
10
1
3
9
8
11
5

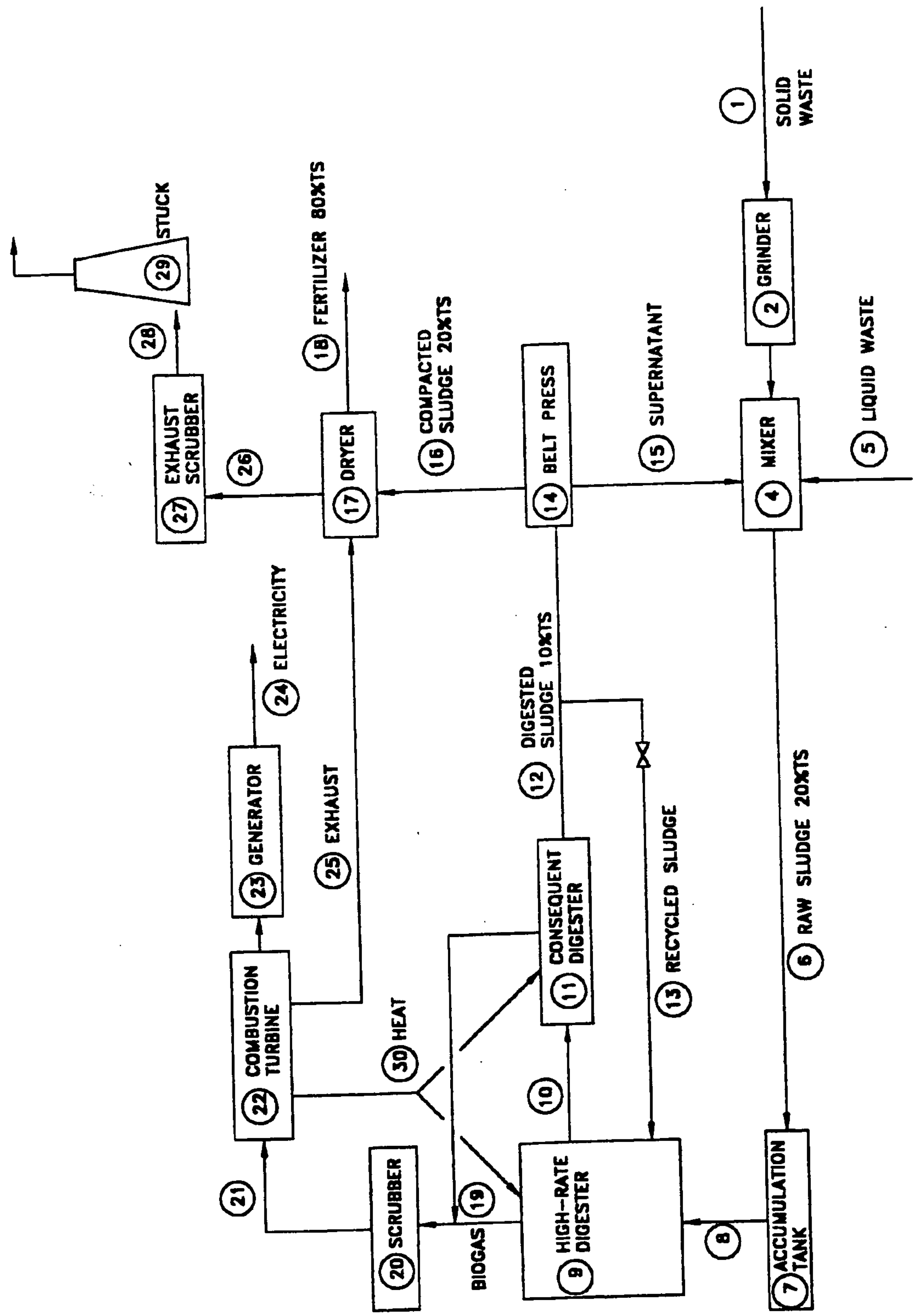

1
SOLID WASTE
2 GRINDER
4 MIXER
5 LIQUID WASTE
6 RAW SLUDGE 20%TS
7 ACCUMULATION TANK
8
9 HIGH-RATE DIGESTER
10
11 CONSEQUENT DIGESTER
12 DIGESTED SLUDGE 10%TS
13 RECYCLED SLUDGE
14 BELT PRESS
15 SUPERNATANT
16 COMPACTED SLUDGE 20%TS
17 DRYER
18 FERTILIZER 80%TS
19
BIOGAS
20 SCRUBBER
21
22 COMBUSTION TURBINE
23 GENERATOR
24 ELECTRICITY
25 EXHAUST
26
27 EXHAUST SCRUBBER
28
29
STUCK
30 HEAT

FIG. 2

THIS PAGE BLANK (USPTO)